

Response of *Bemisia argentifolii* (Homoptera: Aleyrodidae) to Imidacloprid Under Greenhouse, Field, and Laboratory Conditions

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ABSTRACT The systemic insecticide imidacloprid has been used successfully to manage *Bemisia argentifolii* Bellows & Perring and whitefly-borne geminivirus on tomato in south Florida and elsewhere. We evaluated plant and whitefly responses to imidacloprid in greenhouse grown tomato, *Lycopersicon esculentum* Miller, transplants and field-grown fresh market staked tomato. Seedlings in transplant trays treated with 1 or 2 mg (AI) per plant applied as a drench were protected from egg deposition for up to 6 wk of exposure to a greenhouse colony of whiteflies. In the field, either 280 or 560 g (AI)/ha of imidacloprid applied to the soil at transplanting provided protection from all whitefly stages and was better than or equal to protection obtained with weekly sprays of organophosphate/pyrethroid insecticide mixtures for up to 9 wk. Movement of geminivirus infection vectored by whitefly adults was suppressed in small plots, indicating that imidacloprid acted rapidly on adults. Treated tomato or eggplant, *Solanum melongena* L. 'Black Beauty', functioned as trap crops by reducing whitefly numbers on adjacent untreated tomato. High application rates and persistence of imidacloprid have combined to increase the likelihood of insecticide resistance and to necessitate the development of an easily reproducible bioassay to facilitate monitoring. A leaf-dip bioassay indicated that the LC₅₀ for 10-d-old whitefly nymphs to imidacloprid was 6.1 mg (AI)/liter and the LC₉₀ was 32.6 mg (AI)/liter. These results could serve as a baseline for whitefly susceptibility in south Florida, given the lack of any previous exposure to imidacloprid of the tested population.

KEY WORDS *Bemisia argentifolii*, imidacloprid, tomato, geminivirus, tomato mottle virus

Bemisia argentifolii BELLOWS & PERRING became a key pest of tomato, *Lycopersicon esculentum* Miller, in Florida soon after its detection on poinsettia in 1986 (Hamon and Salguero 1987). Direct damage and effects of the whitefly-borne tomato mottle geminivirus (ToMoV) plus control costs in Florida alone were estimated at \$141 million for the 1990-1991 seasons (Schuster et al. 1996). A marked reduction in whitefly incidence was noted in 1994, coincident with availability and widespread use of the systemic chloronicotinyl insecticide imidacloprid (Stansly 1996). Palumbo and Kerns (1994) and Palumbo et al. (1996) reported field efficacy of this material against *B. argentifolii* in lettuce. However, little published information exists to verify a causal relationship between regional use patterns of imidacloprid on tomato and the precipitous drop in whitefly populations and associated geminivirus that was observed subsequently (Stansly 1996).

Imidacloprid is either applied to tomato transplants in the greenhouse or immediately after planting when susceptibility to ToMoV is greatest (Schuster et al. 1996). The 1st objective of the current study was to determine the optimal timing and application rate of imidacloprid to transplants. The 2nd objective was to

evaluate the effectiveness of imidacloprid for management of *B. argentifolii* on vegetable crops.

Given the widespread use of imidacloprid for management of *B. argentifolii* on vegetables in Florida, a simple and reliable bioassay was required to monitor whitefly susceptibility to imidacloprid and thereby provide early warning of possible development of resistance. Cahill et al. (1996) reported reliable results from bioassays of adult *B. tabaci* (Gennadius), responding to disks cut from cotton, *Gossypium hirsutum* L., leaves that had imbibed solutions of imidacloprid hydroponically. Their method had the advantage of using normal systemic delivery of imidacloprid to the target. However plant-related factors such as phytotoxicity could affect uptake and cause results to vary, as observed at high rates and hydroponic intervals in a study by Williams et al. (1996) that used the same method. Furthermore, hydroponic assays published thus far provide no measure of nymphal response. Therefore, a 3rd objective of our study was to develop a bioassay for whitefly nymphs based directly on concentration of active ingredient that could serve as a baseline for susceptibility to imidacloprid.

Materials and Methods

Plants. Several varieties of tomato, *L. esculentum*, were used in the experiments: 'Florida Lanai' for laboratory bioassay, 'Colonial' for greenhouse transplant

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trials, and 'Sunny', 'Sunbeam', or 'Agriset' for field trials.

Insecticide. Imidacloprid (Admire 2 F [flowable], 21.4% of imidacloprid, Bayer, Kansas City, MO) was tested in concentrations of 0, 1.75, 3.5, 7, 17.5, 35, and 70 mg (AI)/liter for the laboratory bioassay. At the recommendation of the manufacturer, concentrations of 0, 1, and 2 mg (AI) per plant were applied to greenhouse transplants as a soil drench with 5 ml of water. Rates tested in the field were 560 g (AI)/ha (0.5 lb [AI]/acre), or 47 mg (AI) per plant in 1992, and 280 g (AI)/ha (1 pint/acre product), or 23.5 mg (AI) per plant in 1994 and 1995, applied with 120 ml (4 oz) of water drenched at the base of each plant within 1 wk of transplanting. In the 1994 field trial, a weekly rotation of endosulfan (Thiodan, 3 EC [emulsifiable concentrate] FMC, Philadelphia PA), 630 g [AI]/ha and a mixture of fenpropathrin (Danitol 2 E [emulsion], Valent, Walnut Creek CA), 224 g [AI]/ha and methamidiphos (Monitor 4 E, [emulsion] 840 g [AI]/ha, Valent) were used for comparison.

Persistence in Tomato Transplants and Plant Response. Tomato was seeded into 392-unit seedling trays filled with Metro Mix 220 and grown by standard procedures (Hochmuth and Vavrina 1997) in an open-sided greenhouse with 250 ppm N supplied by Nutrilife 20-20-20 applied weekly through overhead irrigation (Miller Chemical, Hanover, PA). The experiment included 2 factors: treatment times (at seeding and 2 and 4 wk after seeding) and rate (1 and 2 mg [AI] imidacloprid per plant) for a total of 6 treatments plus an untreated control. Two trays were used per replicate, with plots consisting of 84 seedlings separated from adjacent plots by a blank row of cells. Eight replications were arranged in a randomized complete block design, 4 of which were seeded on 1 February, and the remaining 4 on 24 February 1995. Imidacloprid was applied as a 5-ml drench into each individual tray cell.

Plants were moved after 4 wk to a closed, air-conditioned glass greenhouse ($\approx 30^{\circ}\text{C}$) used to house a colony of *B. argentifolii* originally obtained from D. J. Schuster (Bradenton, FL) in 1990 and identified by T. Perring (University of California, Riverside). Collards and tomato used as hosts were grown in 15-cm pots filled with Metro-Mix 300 (Grace Sierra, Horticultural Products, Milpitas, CA) and fertilized weekly with Peters Professional Water-soluble fertilizer (20-20-20, N-P-K) (Scotts, Allentown, PA). Seedling trays were moved daily to counteract possible bias of aggregated dispersion, each time shaking adjacent tomato and collard plants to encourage whiteflies to alight on the seedlings. Evaluations of 10 randomly selected plants per plot began 14 d after 1st exposure to whiteflies and continued at 7-d intervals for 4 wk. Ten plants per plot were sampled 5 times at weekly intervals. Whitefly eggs and nymphs were counted under a stereoscopic microscope (20-40 \times magnification) in two, 0.25-cm² areas on either side of the midrib near the base of 6 leaflets taken from the 2 oldest leaves of each seedling to give a total leaf area of 30 cm² per plant. The 10 plants evaluated for white-

fly nymphs were placed in a paper bag and desiccated in a 80EC drying oven, ground, and weighed to evaluate treatment effects on growth rate.

Field Tests. Spring 1992. Twelve raised beds 0.9 m wide on 1.8-m centers were fertilized with 570 kg/ha of 5-16-8 (N-P-K) mixed into the bed and 1,065 kg/ha of 19-0-30 placed in 2 bands, 1 on either side of the row. Beds were fumigated with Vapam (37% metham-sodium) at the rate of 375 liter/ha and covered immediately with black polyethylene. Transplants were set 3 wk later at a 51-cm spacing on 23 March. Plots were 6.5 m long, 3 rows wide, and separated at either end by a 1-m buffer. Two seedlings infected with ToMoV were planted in the center row of each plot to provide a uniform source of inoculum. The seedlings had been infected by exposure to viruliferous whiteflies for 2 wk inside a cage (60 by 60 by 60 cm) containing infected tomato plants. Imidacloprid was applied 2 d after transplanting at a rate of 580 g (AI)/ha by drenching individual plants with 43 mg of imidacloprid diluted in 10 ml of water. Plants were staked, tied, and pruned 3 times, and weekly maintenance sprays of Manzate 200 (DuPont, Wilmington, DE, 1.68 kg/ha), Tri-basic Copper (3.36 kg/ha), Bravo (ISK Biosciences, Mentor, OH, 2.34 liter/ha), and Dipel (Abbott, N. Chicago, IL, 1.12 kg/ha) were applied to control disease and lepidopterous pests. Experimental design was a randomized complete block with 4 replications and 12 treatments, 3 of which are reported here to compare effects of imidacloprid with a conventional spray rotation and an untreated control. Weekly sprays of a mixture of Danitol-Monitor (fenpropathrin, 224 g [AI]/ha, and methamidiphos, 840 g [AI]/ha) commenced on 24 April 1992 for 7 wk. Sampling for whitefly adults and eggs was initiated 29 d after transplanting, and for nymphs, 40 d after transplanting. Whitefly adult populations were monitored by striking 5 randomly selected plants per plot over a black nonstick baking pan, (31 by 20 cm), termed a "beat pan," coated with a thin layer of vegetable oil and dish detergent (9:1). Whitefly eggs, nymphs, and pupae were monitored every other week on 10 randomly selected plants by examining four, 1-cm² disks per leaf sample, 2 on each side of the midvein. Eggs were counted on 10 leaflets from the youngest, fully expanded leaves (usually the 3rd leaf from the apex). Nymphs and pupae generally were sampled from the 7th leaf, depending on the results of presample observations to determine the youngest leaves upon which pupal exuviae could be found. ToMoV was identified by symptoms and verified by dot blot hybridization analysis (Polston et al. 1993). Incidence of ToMoV was determined by examining all plants at weekly intervals. All fruit of marketable size on 10 randomly selected plants was harvested twice. Marketable fruit was graded on a commercial table with weights and numbers recorded and unmarketable fruit was counted and weighed.

Spring 1994. Four tomato beds designated for this experiment were randomly chosen from among 8 identically prepared beds in a field of 16 pairs of drip-irrigated beds of tomato and other whitefly host

plants [cucumber, *Cucumis sativus* L., zucchini squash, *Cucurbita pepo* L., watermelon, *Citrullus lanatus* (Thunberg) Matsumura & Nakai, and winter melon, *Cucumis melo ndorus* Naudin] at Southwest Florida Research & Education Center. Beds 72 m long and 0.9 m wide on 1.8-m centers were fumigated with a 240 kg/ha of a 67:33 mixture of methyl bromide:chloropicrin, and covered with a mulch of black polyethylene film. Four pairs of beds representing 4 replications were separated by a 4.5-m drive middle with 6.4 m between beds in adjacent plots. Rows adjacent to drive middles were planted on 25 February to tomato (Sunbeam) with no inoculum of ToMoV provided. Rows were divided into 5 plots assigned to 1 of 4 treatments in a completely randomized block: (1) untreated control (2 plots per replicate); (2) a conventional insecticide rotation consisting of 3 weekly sprays of endosulfan (Thiodan, 630 g [AI]/ha) rotated with a mixture of Danitol (224 g [AI]/ha) and Monitor (841 g [AI]/ha) also applied 3 times; (3) imidacloprid applied at a rate of 280 g (AI)/ha (23.4 mg [AI] per plant) diluted in 120 ml (4 oz) of water drenched at the base of each plant with a CO₂ backpack sprayer; and (4) a rotation of biorational insecticides not reported here. Weekly samples for whitefly immatures from 29 March to 3 May consisted of a single leaf from 3 randomly selected plants per plot and processed as above to give a 12-cm² leaf area sample. Adult whiteflies were monitored with a beat pan as described above from 8 randomly selected plants per plot. All tomato plants were examined 7, 14, 22, and 16 April and 6 May, noting those exhibiting typical symptoms of ToMoV; yellow mottling and upward curling leaves, shortening of internodes and dwarfing.

Spring 1995. Sixteen pairs of drip-irrigated beds prepared as above were separated on 1 side by a 4-m drive and on the other by a 5-m buffer strip. The drive-side row was divided into four, 18-m plots, planted to tomato ('Agriset') on 19 January and received no imidacloprid. The buffer-side row was divided into four, 18-m plots, 2 of which were randomly selected for planting to tomato and the other 2 to eggplant, *Solanum melogena* L. 'Black Beauty'. One tomato plot and 1 eggplant plot were randomly selected to receive an application of imidacloprid at a rate of 280 g (AI)/ha (23.5 mg [AI] per plant) applied in 120 ml (4 oz) of water drenched at the base of each plant with a CO₂ backpack sprayer. The other 2 plots received no imidacloprid. Thus, drive-side rows had 4 treatments: (1) treated tomato, (2) treated eggplant, (3) untreated tomato, and (4) untreated eggplant. To test the effect of adjacent treated or untreated companion crops, buffer-side rows of untreated tomato were considered to have 4 treatments because of proximity to particular plots in the adjacent drive-side row. Monitoring for adults beginning on 6 March was repeated at 7- to 10-d intervals for 8 wk, and weekly monitoring of immature whiteflies began on 16 March and continued for 8 wk. Monitoring procedures were the same as 1994.

Laboratory Bioassay. Whitefly-free tomato plants were placed in the whitefly colony for a 24-h infestation period after agitating adjacent plants to assure

uniform distribution of whiteflies. Plants were then disinfested of adult whiteflies with a vacuum cleaner and maintained in whitefly-free cages for 10 d to obtain 2nd and 3rd instars. Tomato leaves (trifoliolate) bearing from 18 to 190 whitefly nymphs were removed from the plants at the base of the petiole and individually dipped in the test solution for 5 s. Treated leaves were drained for 5 min on paper toweling, then placed individually, petiole first, in 20-ml water-filled glass vials. Leaves in glass vials were placed in individual clear plastic cup cages (1.9 liter) and incubated at 25 ± 2°C, 70 ± 5% RH, and a fluorescent illumination photoperiod of 14:10 (L:D) h. Water was replenished daily in the glass vials as needed. Each concentration had 10 replicates (tomato trifoliolate) with a total of 3,810 whitefly nymphs tested. Whitefly nymphs were examined 4 d after treatment when dead and live nymphs could be easily distinguished under a binocular stereo microscope at 20–40× magnification.

Data Analysis. Numbers of whitefly eggs and nymphs on tomato transplant seedlings were analyzed as repeated measures of a split-plot design, by using the rate × replication and timing × replication mean squares as error terms to test for effects of rate and treatment timing respectively. Two analyses were conducted, one that included the untreated control and the other that excluded the control and only compared imidacloprid treatments. The 2nd analysis was conducted because of disparity in number of whiteflies between control and imidacloprid treatments that masked differences among the latter. Numbers of whitefly eggs, nymphs, and adults on tomato or on eggplant in field trials were subjected to analysis of variance (ANOVA) based on a split-plot design with measurement over dates and means separated by using the least significant difference (LSD) at $P = 0.05$ (SAS Institute 1995). Data from laboratory bioassays with imidacloprid were analyzed by using POLO (LeOra Software 1994) to obtain LC₅₀ and LC₉₀ estimates for 2nd instars of *B. argentifolii*.

Results

Persistence in Tomato Transplants and Plant Response. Neither rate of imidacloprid eliminated whitefly eggs from seedling tomato, although oviposition as determined by number of eggs on the treated plants relative to untreated plants was significantly reduced early in the trial (Table 1). Effects among imidacloprid treatments on numbers of both eggs and nymphs > 6 wk exposure of transplants to whiteflies were significant (eggs, $F = 4.06$; $df = 2, 228$; $P = 0.045$ and nymphs, $F = 10.5$; $df = 2, 228$; $P < 0.0014$). Comparing rates, the number of eggs was more similar (0.49 and 0.35/cm² leaf area, respectively) than the number of nymphs (0.025 and 0.0058/cm² leaf area). Application timing had less effect on number of eggs than did rate of insecticide. Significant differences ($P < 0.01$) among application times were observed only in the 4th and 6th wk of exposure when more eggs were seen on plants treated at time of seeding than on plants treated at 2 or 4 wk after seeding.

Table 1. Effect of imidacloprid on *B. argentifolii* eggs and nymphs on tomato transplants treated at seeding, and 2 and 4 wk after seeding

Treatment time	Rate, mg per plant	Weeks after treatment				
		6th wk	7th wk	8th wk	9th wk	10th wk
Whitefly eggs/30-cm ² leaf area						
Seeding	0	24.0 ± 2.1a	24.7 ± 2.1a	21.7 ± 2.4a	17.2 ± 1.9a	16.5 ± 2.3a
	1	15.3 ± 2.7bA	16.3 ± 2.1bA	17.8 ± 2.2aA	13.5 ± 1.5aA	17.5 ± 3.7aA
	2	11.5 ± 1.3bA	9.4 ± 1.0bB	14.4 ± 2.0aA	12.8 ± 2.3aA	14.4 ± 2.4aA
2 wk	0	24.0 ± 2.1a	24.7 ± 2.1a	21.7 ± 2.4a	17.2 ± 1.9a	16.5 ± 2.3a
	1	11.1 ± 1.4bA	11.2 ± 1.1bA	18.5 ± 3.2abA	12.8 ± 1.5abA	13.4 ± 3.2aA
	2	9.7 ± 1.2bA	9.2 ± 1.8bA	11.3 ± 1.6bB	7.8 ± 0.9bB	5.0 ± 0.6bB
4 wk	0	24.0 ± 2.1a	24.7 ± 2.1a	21.7 ± 2.4a	17.2 ± 1.9a	16.5 ± 2.3a
	1	12.0 ± 1.6bA	11.4 ± 1.4bA	11.4 ± 1.1bA	19.4 ± 2.4aA	13.0 ± 3.7aA
	2	8.8 ± 1.0bA	8.3 ± 1.0bA	7.7 ± 1.4bB	7.8 ± 0.8bB	12.0 ± 0.1aA
Whitefly nymphs/30 cm ² leaf area						
Seeding	0	0	2.6 ± 0.3a	2.9 ± 0.3a	3.0 ± 0.4a	2.0 ± 0.4a
	1	0	0.2 ± 0.1bA	0.3 ± 0.1bA	0.4 ± 0.1bA	0.8 ± 0.3bA
	2	0	0.1 ± 0.0bA	0.1 ± 0.1bA	0.3 ± 0.1bA	0.5 ± 0.2bB
2 wk	0	0	2.6 ± 0.3a	2.9 ± 0.3a	3.0 ± 0.4a	2.0 ± 0.4a
	1	0	0.1 ± 0.1bA	0.3 ± 0.1bA	0.1 ± 0.1bA	0.7 ± 0.3bA
	2	0	0.1 ± 0.0bA	0.0 ± 0.0bB	0.2 ± 0.1bA	0.0 ± 0.0bB
4 wk	0	0	2.6 ± 0.3a	2.9 ± 0.3a	3.0 ± 0.4a	2.0 ± 0.4a
	1	0	0.2 ± 0.1bA	0.2 ± 0.1bA	0.1 ± 0.0bA	0.8 ± 0.3bA
	2	0	0.0 ± 0.0bA	0.0 ± 0.1bB	0.1 ± 0.0bA	0.1 ± 0.0bB

Means ± SE in the same column with the same letters did not differ significantly ($P > 0.05$, LSD [SAS Institute 1995]).
 " Lower case letters refer to comparisons among all rates (0, 1, and 2 mg per plant), whereas upper letters refer to comparison among the 2 non-zero rates.

Estimates of dry matter accumulation from tomato transplants were lower in weeks 7, 8, and 9 for plants receiving the high rate of imidacloprid compared with the untreated control, but no effect of the low rate was observed (Table 2). Thus, the high rate of imidacloprid appeared to retard plant growth. Dry matter plants at 9 wk and over all weeks of plants receiving imidacloprid 4 wk after seeding was significantly reduced compared with untreated plants (Table 2). Foliar evidence of phytotoxicity consisted of necrosis around leaf margins and was most notable at the higher treatment rate. Leaf necrosis was observed within 3 d of application to seedlings and within 2 wk of application at seeding.

Field Trials. Spring 1992. Whitefly eggs and nymphs increased steadily on untreated plants, especially toward the end of the trial (Fig. 1 A and B). The imidacloprid drench applied at ransplanting was as effective, through 56 d after application, at suppressing

the increase as weekly sprays of Danitol + Monitor, and provided significant protection (compared with the control) for 83 d after application. A sharp increase in adults was detected, most notably in the control, when crops were 37 d old (29 April, Fig. 1C). However, egg numbers remained low with both insecticide treatments (Fig. 1A). Treatment effects on whitefly adults were significant ($P < 0.05$) on all sample dates except 43 d after transplanting (5 May). At no time were significant differences observed between numbers of adults on plants treated once with imidacloprid and plants sprayed weekly with the Danitol-Monitor standard. Incidence of ToMoV was low and without significant treatment effects. Effects on yield were not significant.

Spring 1994. Significant treatment effects on adults and immatures (nymphs plus pupae) were observed on all dates except for the earliest sample of adults (Fig. 2A and B). Fewer whitefly adults were observed

Table 2. Effect of imidacloprid application timing and concentration on dry weight (g ± SE) of tomato transplants

	Dry wt (g ± SE) per 10 plants					
	Week 6	Week 7	Week 8	Week 9	Week 10	Overall mean
Application rate (mg [AI] per plant)						
0	0.71 ± 0.03a	1.16 ± 0.09a	1.54 ± 0.09a	2.61 ± 0.26a	3.76 ± 0.34a	2.09 ± 0.20a
1	0.72 ± 0.02a	1.12 ± 0.05a	1.55 ± 0.07a	2.39 ± 0.19ab	3.71 ± 0.25a	2.00 ± 0.16a
2	0.69 ± 0.03a	0.98 ± 0.05b	1.34 ± 0.10b	2.17 ± 0.22b	3.17 ± 0.29a	1.75 ± 0.14a
Application timing						
None	0.71 ± 0.03a	1.16 ± 0.09a	1.54 ± 0.09a	2.61 ± 0.26a	3.76 ± 0.34a	2.09 ± 0.20a
At seeding	0.68 ± 0.01a	1.10 ± 0.09a	1.46 ± 0.14a	2.57 ± 0.29a	3.67 ± 0.21a	1.94 ± 0.19ab
2 wk	0.71 ± 0.04a	1.04 ± 0.07a	1.46 ± 0.10a	2.18 ± 0.25ab	3.52 ± 0.42a	1.90 ± 0.20ab
4 wk	0.72 ± 0.04a	1.02 ± 0.07a	1.42 ± 0.11a	2.09 ± 0.19b	3.18 ± 0.32a	1.79 ± 0.17b

Means ± SE in the same column within A or B sections followed by the same letter(s) did not differ significantly ($P = 0.05$, LSD [SAS Institute 1995]).

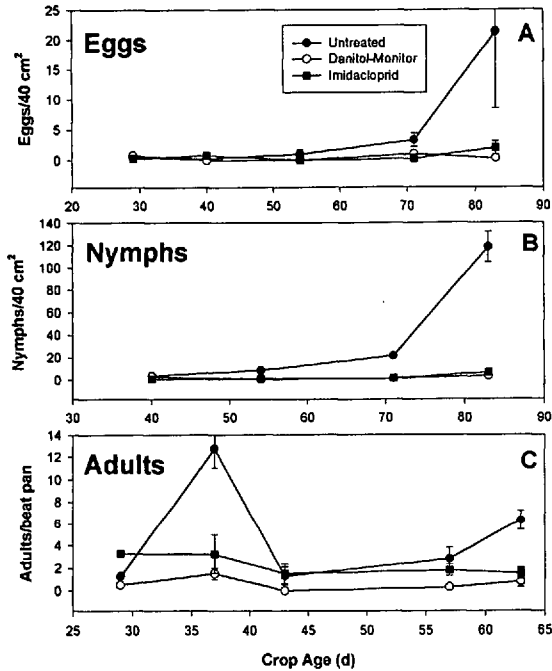


Fig. 1. *B. argentifolii* eggs (A), nymphs (B), and adults (C) from staked tomato plants treated with imidacloprid (560 g [AI]/ha or 47 mg [AI] per plant) as a drench 2 d after transplanting compared with 7 foliar applications of Danitol (224 mg [AI]/ha plus Monitor, 841 g [AI]/ha) from 24 April, and an untreated control (Immokalee, FL, 1992). Bars indicate standard error of the mean.

beginning 12 April and over all sampling dates ($F = 50.03$; $df = 2, 547$; $P = 0.0001$) on imidacloprid-treated plants (4.9 ± 1.0 , mean \pm SE) compared with the control (31.2 ± 2.0) or with plants sprayed weekly with the conventional standard of Danitol + Monitor rotated with Thiodan (24.3 ± 3.8). Differences in numbers of nymphs among treatments were highly significant ($F = 107.32$; $df = 2, 482$; $P = 0.0001$), with seasonal means of 38 ± 12.9 on untreated plants compared with 2.3 ± 0.8 on sprayed plants, and 1.9 ± 0.6 on imidacloprid-treated plants. Mean weekly increase of plants symptomatic for ToMoV was dramatically lower where imidacloprid had been applied ($5.2 \pm 6.3\%$) compared with sprayed ($14.5 \pm 12.0\%$), or untreated plants ($16 \pm 12.4\%$), with no significant differences between sprayed and untreated plants ($P > 0.05$, Fig. 2C). Yield was greatest from sprayed plants (1.6 kg, SE = 0.095) compared with control plants or imidacloprid-treated plants (0.97 kg, SE = 0.95 and 0.98 kg, SE = 0.45, respectively) primarily because of damage caused by tomato pinworm, *Keiferia lycopersicella* (Walsingham). Yield evaluation did not include plants infected with ToMoV, which typically depresses yield, especially when infection occurs early in the plant cycle (Schuster et al. 1996).

Spring 1995. Whitefly numbers were down by an order of magnitude compared with 1994 and ToMoV incidence was almost nothing, in part because planting

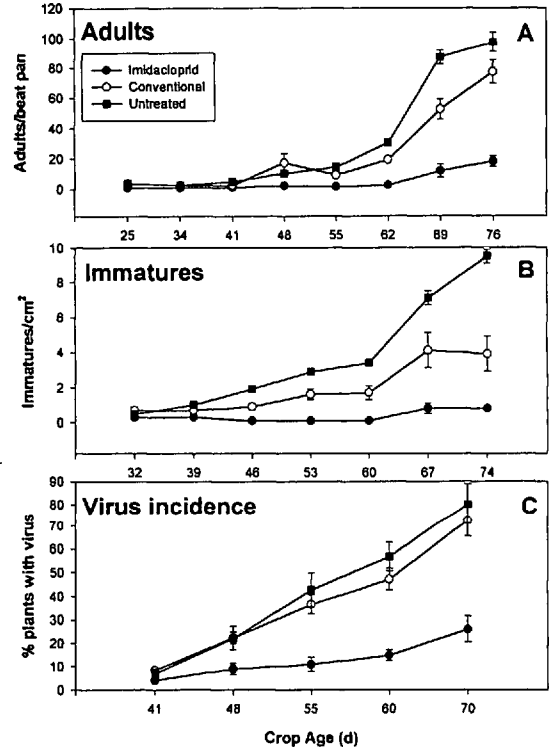


Fig. 2. *B. argentifolii* adults (A) and immatures (B), and weekly increases in percentage infection (C) in staked tomato after application of imidacloprid (280 g [AI]/ha or 23.5 mg [AI] per plant) compared with a weekly rotation of Thiodan (630 g [AI]/ha) and Danitol (224 mg [AI]/ha) plus Monitor (841 g [AI]/ha), and an untreated control (Immokalee, FL, 1994).

occurred a month earlier, but also because of low populations areawide. Nevertheless, significant effects of imidacloprid on whitefly infestation were observed (immatures; $F = 61.01$; $df = 3, 432$; $P = 0.0001$ [Fig. 3A]; adults; $F = 140.12$; $df = 3, 883$; $P = 0.0001$ [Fig. 4A]). The standard rate of 280 g (AI)/ha applied at planting held nymphal and egg density relatively unchanged through the 93-d experiment. Untreated tomato next to treated tomato or eggplant had fewer whiteflies than plants next to untreated plants, with significantly fewer immatures at 70 d (3 March) and 90 d (19 April, Fig. 3B) and significantly fewer adults at 95 d (24 April, Fig. 4B). Again, tomato pinworm infestation obviated meaningful comparisons of whitefly impact on yield.

Laboratory Bioassays. The LC_{50} was estimated at 6.096 mg (AI)/liter (95% FL; 3.404–9.240) and LC_{90} of 32.645 mg (AI)/liter (95% FL; 20.469–44.850) (Fig. 5). The chi-square value was 12.3, significant at $P = 0.01$ (chi-square with 4 degrees of freedom 13.28), indicating some departure from the probit model, probably at low and high concentrations. The whitefly population had never been exposed to imidacloprid, so these results could be considered to provide a baseline for *B. argentifolii* susceptibility to imidacloprid in south Florida.

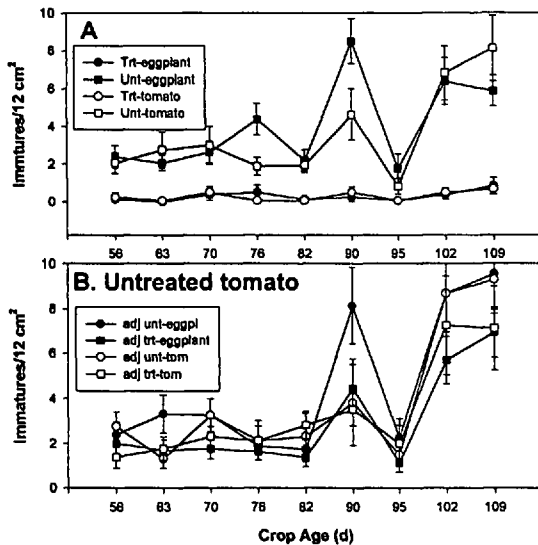


Fig. 3. *B. argentifolii* nymphs per 12-cm² leaf area on staked tomato leaves after application of imidacloprid (280 g [AI]/ha, or 23.5 mg [AI] per plant). (A) Treated tomato, treated eggplant, untreated tomato, and untreated eggplant. (B) Untreated tomato adjacent to the above-treated plants (Immokalee, FL, 1995).

Discussion

Our results with transplants showed tradeoffs between phytotoxicity and insecticidal activity with different application rates and timing. Higher rates resulted in better activity, but also reduced plant growth. Optimal whitefly control and plant growth was ob-

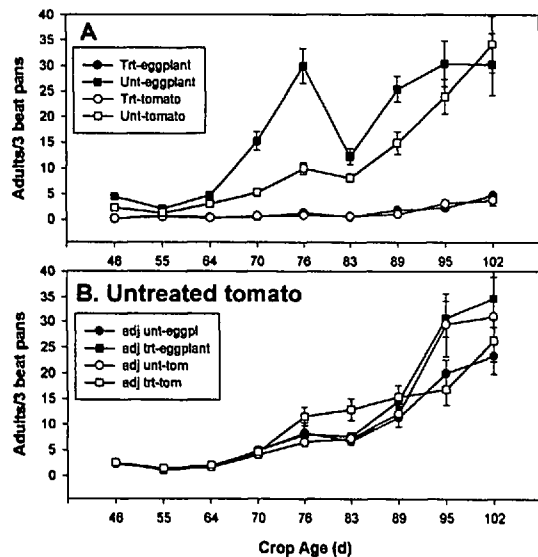


Fig. 4. *B. argentifolii* adults per 3 beat pans after application of imidacloprid (280 g [AI]/ha or 23.5 mg [AI] per plant). (A) Treated tomato, treated eggplant, untreated tomato, and untreated eggplant, (B) Untreated tomato adjacent to the above-treated plants (Immokalee, FL, 1995).

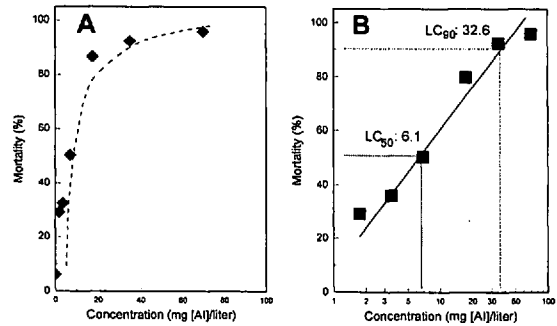


Fig. 5. Toxicity of imidacloprid to 2nd instars of *B. argentifolii* on tomato leaves. (A). Concentrations not transformed to a log scale. (B). Concentrations log transformed. Probit analysis parameters: LC₅₀ = 6.096 mg (AI)/liter (95% FL, 3.404–9.240); LC₉₀ = 32.6 mg (AI)/liter (95% FL, 20.469–8399.44.850); slope = 1.759 (± 0.048).

tained by delaying application for 2 wk after seeding. However, this practice would leave plants exposed to virus infection for the 1st part of the transplant cycle, so application at seeding would be advisable where the presence of viruliferous whiteflies in the plant house was suspected.

The bioassay of nymphs gave consistent results, although they did depart somewhat from the probit model as determined by a significant chi-square. Consistent results also have been reported from bioassays of adults on cotton disks (Cahill et al. 1996, Williams et al. 1996) or seedlings (Prabhaker et al. 1995) treated with imidacloprid hydroponically. However, nymphs are also a target of imidacloprid treatments, and nymphal responses may differ from adult responses. Therefore, a complete bioassay should include nymphs. Furthermore, convenience may favor bioassay of nymphs in a monitoring program designed to detect changes in susceptibility to imidacloprid or other insecticides among field populations.

Imidacloprid treatment reduced geminivirus occurrence in spite of small plot size and the consequent likelihood of viruliferous whiteflies moving among plots. Transmission efficiency on tomato of another bipartite geminivirus, chino del tomate, increased from 8.3 to 31 to 98% with increasing inoculation access periods of 2 to 4 to 24 h, respectively (Brown and Nelson 1988). Assuming similar parameters for ToMoV, imidacloprid must have repelled colonizing adults or killed them quickly enough to have effectively suppressed ToMoV movement from untreated plots to treated plots.

Our data support the characterization of imidacloprid as a powerful tool for managing silverleaf whitefly on vegetables in both transplant house and field. Residual effects of a single application may last up to 3 mo and virus movement can be suppressed. These advantages have not been lost on growers and the product has been widely used. Coincident with this use in southwestern Florida has been a dramatic areawide reduction of whitefly populations and virus incidence (Stansley 1996). Intensive use and long residual activity

are factors that escalate the risk of rapid selection for resistance and therefore, the urgency of monitoring whitefly sensitivity to this product.

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